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Tunnel boring machine selection in railway project - case study

Debela Deme

Lecturer in University of Gondar, Department of Civil Engineering, University of Gondar, Gondar, Ethiopia,
Phone: +251913834664
Email: Debela.Deme@gmail.com

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ABSTRACT

Tunneling was an approach used to excavate and construct tunnel. Most engineers agree that tunnel length, tunnel cross section, tunnel depth, geotechnical condition and level of water table were the most probable factor governs the selection of tunnel boring machine or tunneling approach. The main purpose of this case study was examining and selecting tunnel boring machine for specified railway project for specified area. The studies use Analytical Hierarchy Process (AHP) for further analysis weight and compare the factors and alternatives. In order to undertake proper tunneling; data collected by engineers on factors govern tunnel boring machine selection can be used as raw input for the analysis of weight of effective factor and influences stability factor. Weight of effective factor for TPM Gripper and Road Header in line with factor of govern tunnel boring machine selection was (0.145, 0.187, 0.187, 0.287, 0.217) and (0.22, 0.194, 0.152, 0.205, 0.229) respectively. Total sum of influences of suitability rating for TBM Gripper and Road Header were 7.0165 and 6.942 respectively. Machine with maximum value of influences of suitability rating was selected for tunneling. As a result; TBM Gripper with 7.0165 influences of suitability rating considered as tunnel boring machine for the project area.

Keywords: Tunneling; Soil; Analytical Hierarchy Process; Weight of effective factor; Influences of suitability rating

Technical Characteristics of Tunneling Area

A Single-track railway project was introduced to connect two cosmopolitan towns (Weldiya and Mekelle) that cover 216km in Ethiopia. Due to the topography of the area was hilly an engineer team recommends Informational Tunneling Method (ITM) to construct tunnels at 202km far from railway origin of Mekelle town. The tunnel was used to connect two points with similar elevation separated by mountain with elevation deference of 50 meter above formation level. The length of the tunnel was approximately 2033m; based on formation and size train expected to navigate across the path. Based on train type and formation the railway engineer recommends diameter of tunnel cross section was 15m. The earth/soil/rock stratum of the area was igneous rock and the tunnel excavation under take above water table level with elevation of 2200m amsl. Based on the availability of tunnel boring machine in Ethiopia TBM Gripper and Road Header were optional for excavation of the tunnel. In line with above information the case study was emphasize on which tunnel boring machine was recommended to undertake tunneling.

1. INTRODUCTION

A tunnel is artificial engineering structures that create an underground passage through a hill, under buildings or etc. (1)In order to develop well-structured tunnel the essential thing was defining tunnel boring machine. Tunneling was an activity done by tunnel boring machine to excavate the strata of earth/soil/rock with a circular cross section. (2) (3)Basically, there were two types of tunnel boring machines. Mostly in used was Open face boring that was suitable for stable soils and Closed-face shielded machines that was suitable for less stable soils. (4)It was widely recognized that most of the total cost and performance of the tunneling projects were determined by the decision making in the conceptual design phase. In this early stage of the project applying multi-criteria optimization can lead to significant savings the tunneling project. (5)The case study uses Applying Multi-Criteria Analyzes (MCA). Methods of multi-criteria analysis include analytical network process (ANP), Technique for Order of Preference by similarity to Ideal Solution (TOPSIS) and Analytical Hierarchy Process (AHP). Accordingly, the studies prefer to use AHP because of suitable technique to weight and compare the factors and alternatives for this study. Therefore decent responds were merged and taken into AHP pairwise comparison application performed. The selection of tunnel boring machine mostly governed by factors related with length of tunnel, cross section of tunnel, depth of tunnel, geotechnical condition of the area and level of water table. (6) (7) (8) Based on those factors tunneling or tunnel boring machine was selected for a given project. In order to define the weight of those factors from suitability of equipment selection chart suitability of equipment selection scores was taken for the analysis of weight of effective factor (WEF). This project has a length of 2033m, radius of 7.5m, elevation deference of 50m, soil strata of an area was igneous rock and tunneling activity was undertake above level of water table. The optional tunnel equipment considered in this case study was TPM Gripper and Road Header. Based on the information depicted below the statistical analysis was run to select tunnel boring machine. Under this circumstance suitability of equipment selection score, weight of effective factor and influences of stability factor was properly analyzed in order to select proper method of tunneling.

2. MATERIAL AND METHODS

During feasibility survey an engineering team collects information about tunneling area and tunnel type considered to be constructed for specified project area. Tunnel length, tunnel crossection, tunnel depth, geotechnical condition and water table level was raw data used to analysis the study. Analytic Hierarchy Process (AHP) method of analysis was used to define the most highly influential method of tunneling for this project. Analytical Hierarchy Process (AHP) was a very commonly used tool for multi-criteria analysis decision making. (9) Analytical Hierarchy Process provides methods of weighing selection criteria with a higher level of objectivity, as items are compared two or more at a time. (9)Suitability of equipment selection score can be collected from suitability equipment selection chart. Weight of effective factor (WEF) for both tunneling method was properly defined in line with suitability of equipment selection score. Based on the weight of effective factor and suitability of equipment selection score the most tunneling method or tunnel boring machine for specified project was selected. The selection of tunneling method was based on the total sum of influences of suitability rating (ISR). Influences of suitability rating equated by multiplication of weight of effective factor by suitability equipment selection score. Tunnel boring machine that have maximum weight of total sum of influences of suitability rating (ISR) was considered as Tunneling method or Tunnel Boring Machine.

Weight of Effective Factor (WEF)

It was the division of suitability equipment selection score of individual factor by total sum of suitability equipment selection score of factors.

$$\text{Weight of Effective factor(WEF)} = \frac{\text{Suitability eqipment selection score of individual factor}}{\text{Total sum of suitablity equipment selection score of factors}}$$

$$\text{WEF} = \frac{\text{Suitability eqipment selection score of individual factor}}{\text{Total sum of suitablity equipment selection score of factors}} \text{.............................. Equ (1)}$$

Based on data collected from the site the suitability equipment selection score was collected from the chart depicted below in line with tunneling method. As a result; suitability equipment selection score for Tunnel Length, Tunnel Cross Section, Tunnel Depth, Geotechnical Condition and Water Table Level factor was (4.9, 6.3, 6.2, 9 and 7.3) for TPM Gripper and (7.5, 6.6, 5.2, 7 and 7.8) for Road Header. So,

Total sum of suitability equipment selection score for Tunneling Machine = Suitability equipment selection score of (Tunnel length +Tunnel cross section+ Tunnel depth+ Geotechnical condition +Water table level)

Therefore; Total sum of suitability equipment selection score for TPM Gripper= Suitability equipment selection score of (Tunnel length +Tunnel cross section+ Tunnel depth+ Geotechnical condition +Water table level)

= 4.9+6.3+6.2+9+7.3 = 33.7

Total sum of suitability equipment selection score for Road Header= Suitability equipment selection score of (Tunnel length +Tunnel cross section+ Tunnel depth+ Geotechnical condition +Water table level)

= 7.5+6.6+5.2+7+7.8 = 34.1

The findings represent the pairwise comparisons among the factors and the scores of alternatives with respect to project conditions. In line with the above information weight of effective factor was analyzed as follow;

Weight of Effective Factor for Tunnel Length (WEFTL)

The tunnel length was factors define tunneling. The tunnel length (L) has been divided into three main categories: L<3000m as short tunneling, 3000m<L>6000m intermediate tunnel, and tunnels with aL>6000m as long tunnels. [10] For More Information See Chart 1 below;

Chart 1 Suitability of equipment with respect to Tunnel Length (TL)

As per information discussed above the length of the tunnel was 2033m that represent short tunnel. From the above chart 1, suitability equipment selection score of tunnel length for TBM Gripper and Road Header was 4.9 and 7.5 respectively.

$$\text{Weight of Effective factor TL } = \frac{\text{Suitability eqipment selection score}}{\text{Total sum of suitablity equipment selection score}}$$

$$\text{WEF of TL for TPM Gripper} = \frac{4.9}{33.7} = 0.145$$

$$\text{WEF of TL for Road Header} = \frac{7.5}{34.1} = 0.220$$

Therefore; weight of effective factor of tunnel length for TBM Gripper and Road Header was 0.145 and 0.220 respectively.

Weight of Effective Factor for Tunnel Cross section (WEFTC)

Tunnel cross section also, factors in tunneling construction equipment selection. Tunnel cross section sizes have been divided into three main groups: Narrow (Micro tunneling) whose opening radius (R<5m), average opening size (5m<R<12m), and large opening (R>12m). [10]For more information see Chart 2 below;

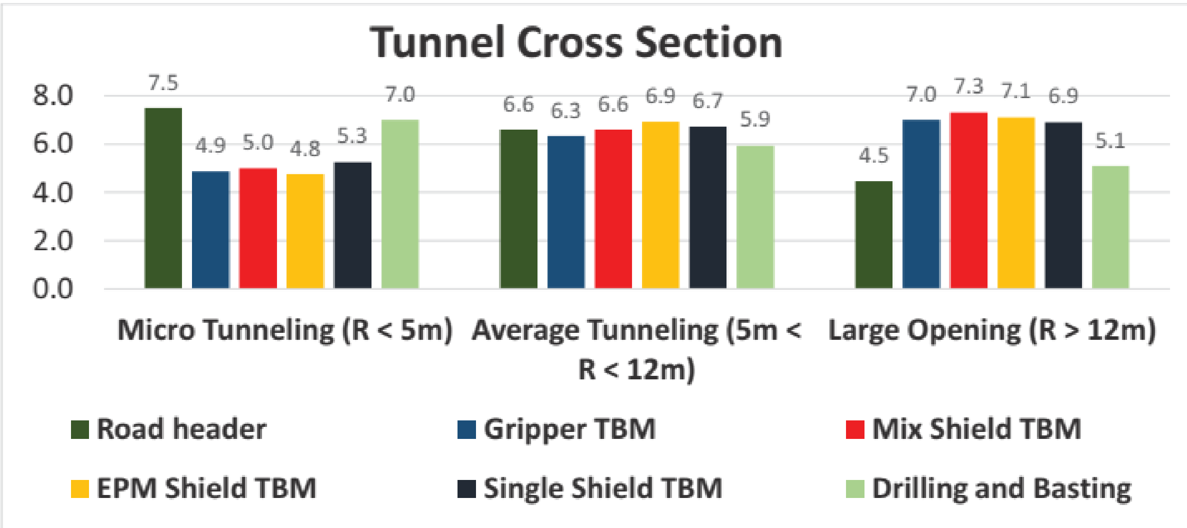


Chart 2 Suitability of equipment with respect to Tunnel Cross Section (TC)

Based on the information discussed above the diameter of the tunnel opening was 15m that depict the radius of tunnel cross section was 7.5m. As a result; the tunnel was average opening size. From the above chart 2, suitability equipment selection score for tunnel cross section of TBM Gripper and Road Header was 6.3 and 6.6 respectively.

$$\text{Weight of Effective factor TC } = \frac{\text{Suitability eqipment selection score of TC}}{\text{Total sum of suitablity equipment selection score}}$$

$$\text{WEF of TC for TPM Gripper} = \frac{6.3}{33.7} = 0.187$$

$$\text{WEF of TC for Road Header} = \frac{6.6}{34.1} = 0.194$$

Therefore; weight of effective factor of tunnel cross section for TBM Gripper and Road Header was 0.187 and 0.194 respectively.

Weight of Effective Factor for Tunnel Depth (WEFTD)

Based on the location and situation of each tunnel, the depths of tunneling excavation vary in a very large range. Three main categories have been defined: very deep (D>200m), average depth (20m<D<200m), and low depth tunnels (D< 20m under the ground level. [10] For more information see chart 3 below;

In line with information discussed above the tunnel excavation was held 50m below ground level. As a result; the tunnel depth was categorized under average depth. From the above chart 3, suitability equipment selection score for tunnel depth of TBM Gripper and Road Header was 6.2 and 5.2 respectively.

$$\text{Weight of Effective factor TD } = \frac{\text{Suitability eqipment selection score of TD}}{\text{Total sum of suitablity equipment selection score}}$$

$$\text{WEF of TD for TPM Gripper} = \frac{6.2}{33.7} = 0.184$$

$$\text{WEF of TD for Road Header} = \frac{5.2}{34.1} = 0.152$$

Therefore; weight of effective factor of tunnel depth for TBM Gripper and Road Header was 0.184 and 0.152 respectively.

Weight of Effective Factor for Tunnel Geotechnical Condition (WEFGC)

Geotechnical condition was one of the most important factors in tunneling selection. Considering variety of soils and rocks, the six main categories have been defined as sedimentary rock, igneous rock, metamorphic rock, sand & gravel, cohesive soil, and highly organic soils. [11]For more information see chart 4 below;

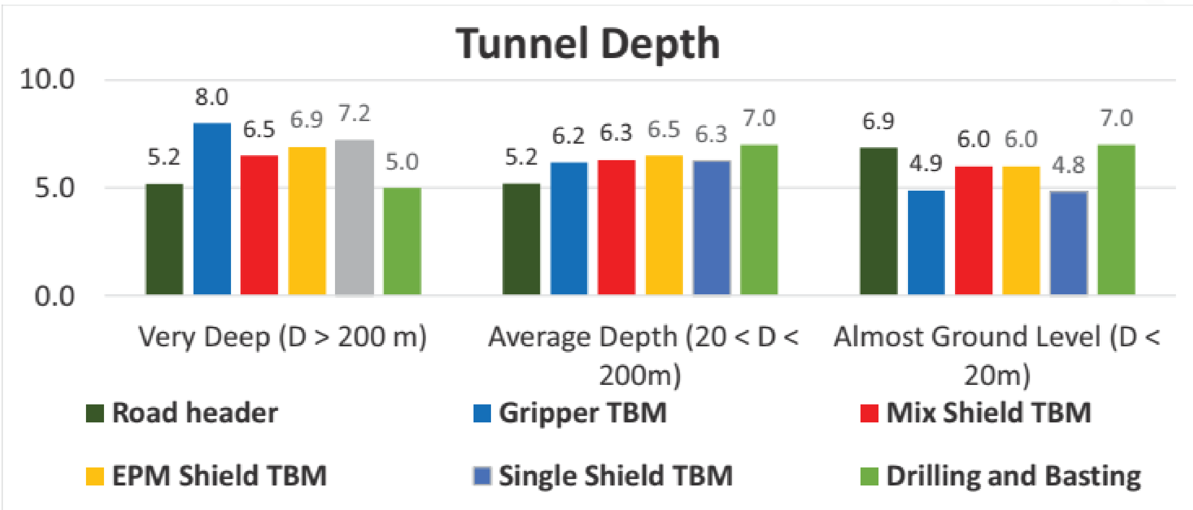


Chart 3 Suitability of equipment with respect to Tunnel Depth (TD)

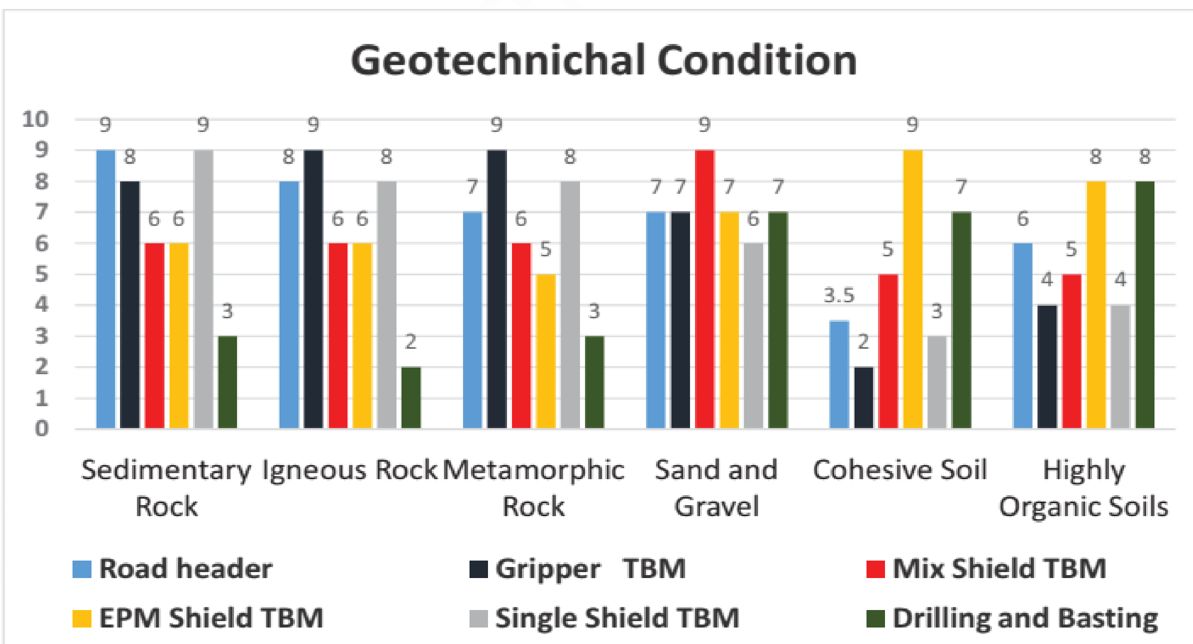


Chart 4 Suitability of equipment with respect to Geotechnical Condition (GC)

Based on the information discussed above the earth/soil/rock stratum of the area was igneous rock. From the above chart 4, suitability equipment selection score for geotechnical condition of TBM Gripper and Road Header was 9 and 7 respectively.

$$\text{Weight of Effective factor GC} = \frac{\text{Suitability eqipment selection score GC}}{\text{Total sum of suitablity equipment selection score}}$$

$$\text{WEF of GC for TPM Gripper} = \frac{9}{33.7} = 0.267$$

$$\text{WEF of GC for Road Header} = \frac{7}{34.1} = 0.205$$

Therefore; weight of effective factor of geotechnical condition for TBM Gripper and Road Header was 0.267 and 0.205 respectively.

Weight of Effective Factor for Water Table Level (WEFWT)

Water table level was also a crucial factor for selecting a tunneling method. The water table level has been grouped in three categories: above the water table, partially submerged, and fully submerged in water. [10]For more information see chart 5 below;

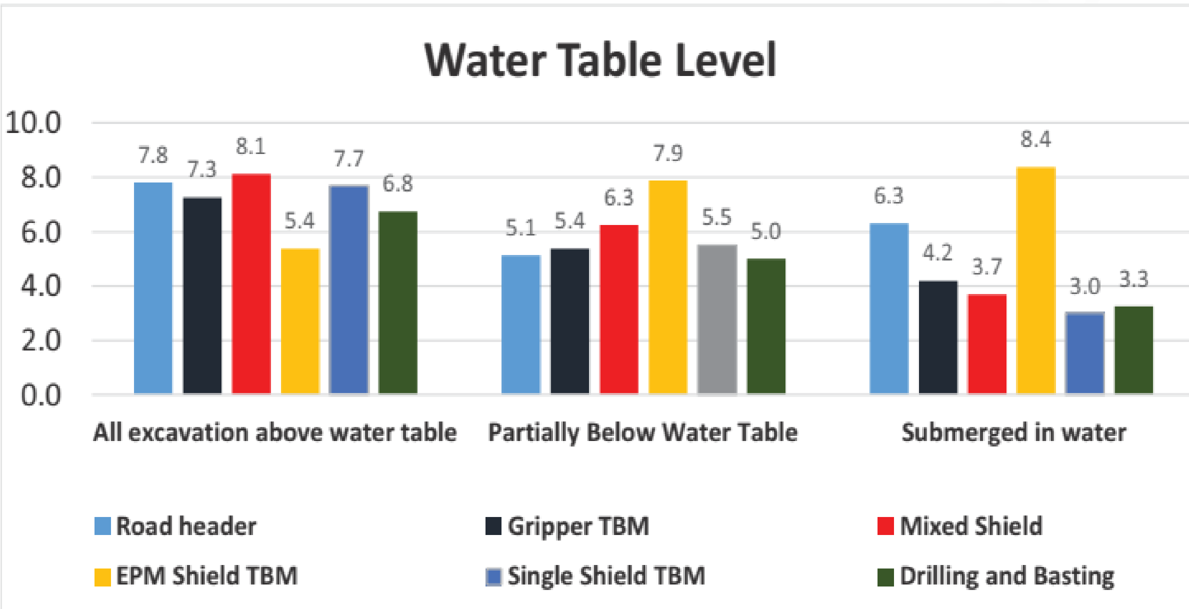


Chart 5 Suitability of equipment with respect to Water Table Level (WT)

Based on the information discussed above tunnel excavation was undertaken above water table level. From the above chart 5, suitability equipment selection score for geotechnical condition of TBM Gripper and Road Header was 7.3 and 7.8 respectively.

$$\text{Weight of Effective factor WT} = \frac{\text{Suitability eqipment selection score of WT}}{\text{Total sum of suitablity equipment selection score}}$$

$$\text{WEF of WT for TPM Gripper} = \frac{7.3}{33.7} = 0.217$$

$$\text{WEF of WT for Road Header} = \frac{7.8}{34.1} = 0.229$$

Therefore; weight of effective factor of water table level for TBM Gripper and Road Header was 0.217 and 0.229 respectively.

To check the significance of the analysis the total sum of weight of effective factor for tunneling method must be equal to 1.

Total weight of effective factor for tunneling method (TWEF) = the sum of weight of effective factor of (Tunnel length+Tunnel Depth+ Tunnel cross section+ Tunnel geotechnical condition +Tunnel water table level)

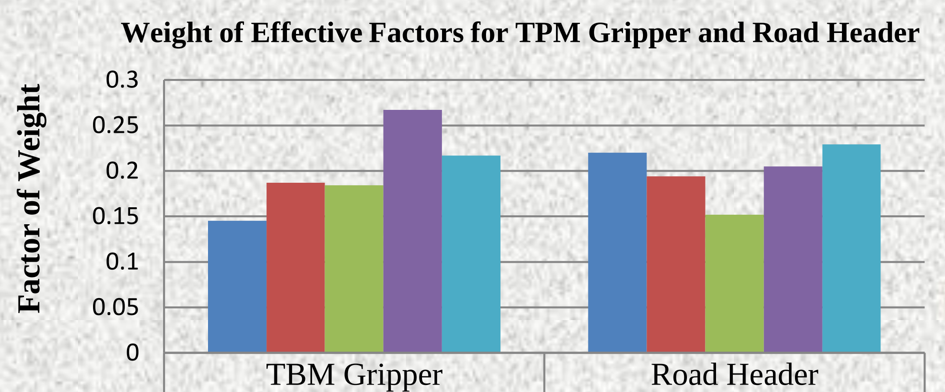
TWEF = WEF of TL +WEF of TC + WEF of TD + WEF of GC + WEF of WT .... Equ (2)

Therefore;

TWEF for TBM Gripper = 0.145 + 0.187 + 0.184 + 0.267 + 0.217 = 1

TWEF for Road Header = 0.220 + 0.194 + 0.152 + 0.205 + 0.229 = 1

As per Analytic Hierarchy Process (AHP) method; the weight of effective factor result represents the relative importance of factors. Chart 6below indicating that geotechnical conditions has greatest influence in tunneling equipment selection with the weight of 0.267, and that water table level with the weight of 0.229 the second largest factor affect the decision making for the selection of tunnel boring machine. The tunnel length with the weight of 0.145 was the less influential in selection of tunnel boring machine.



	TBM Gripper	Road Header
Tunnel Length	0.145	0.22
Tunnel Cross Section	0.187	0.194
Tunnel Depth	0.184	0.152
Geothechnical Condition	0.267	0.205
Water Table Level	0.217	0.229

Chart 6 Weight of Effective Factor for TBM Gripper and Road Header using AHP

Influences of Suitability Rating (ISR)

Influences of suitability rating used to rate the suitability of the tunneling machine. Influence suitability rating was analyzed by the multiplication of weight of effective factor by suitability equipment selection score. The mail goal of influences of suitability rating was to define the most preferable tunneling method. In order to select the tunnel boring machine the sum of influences of suitability rating computed. The maximum weight of total sum of influences of suitability rating defines the most likely method of tunneling for specified project.

Influences of Suitability Rating (ISR) = Weight of Effective Factor (WEF)*Suitability Equipment Selection Score (SESS)

ISR = WEF*SESS .... Equ (3)

Total sum of Influences of Suitability Rating (TISR) = ∑ Influences of Suitability Rating (ISR) of (Tunnel length (TL) +Tunnel Cross section (TC) +Tunnel Depth (TD) +Geotechnical Condition (GC) +Water Table level(WT))

TISR of TPM Gripper = ∑ISF of TPM Gripper (TL+TC+TD+GC+WT)

TISR of Road Gripper = ∑ISF of Road Gripper (TL+TC+TD+GC+WT)

TBM Gripper Influences of Suitability Rating (ISR)

In order to define influences of suitability rating of TBM Gripper; suitability equipment selection score and weight of effective factor of TBM Gripper was depicted below on table 1.

Tunnel Length (TL)

ISR of tunnel length = WEF of tunnel length*SESS of tunnel length

ISR of TL = WEF of TL*SESS of TL

ISR of TL = 0.145*4.9

ISR of TL= 0.7105

Table 1 Suitability equipment selection score and Weight of effective factor of TBM Gripper

TBM Gripper		
Factors	Suitability Equipment Selection Score (SESS)	Weight of Effective Factor (WEF)
Tunnel Length (TL)	4.9	0.145
Tunnel Cross Section (TC)	6.3	0.187
Tunnel Depth (TD	6.2	0.184
Geotechnical Condition (GC)	9	0.267
Water Table Level (WT)	7.3	0.217

Tunnel Cross Section (TC)

ISR of tunnel cross section = WEF of tunnel cross section*SESS of tunnel cross section

ISR of TC = WEF of TC*SESS of TC

ISR of TC = 0.187*6.3

ISR of TC= 1.1781

Tunnel Depth (TD)

ISR of tunnel depth = WEF of tunnel depth*SESS of tunnel depth

ISR of TD = WEF of TD*SESS of TD

ISR of TD = 0.184*6.2

ISR of TD= 1.1408

Geotechnical Condition (GC)

ISR of geotechnical condition = WEF of geotechnical condition*SESS of geotechnical condition

ISR of GC = WEF of GC*SESS of GC

ISR of GC = 0.267*9

ISR of GC = 2.403

Water Table Level (WT)

ISR of water table level = WEF of water table level*SESS of water table level

ISR of WT = WEF of WT*SESS of WT

ISR of WT = 0.217*7.3

ISR of WT = 1.5841

Therefore; the total sum of influences of suitability rating (TISR) for TBM Gripper was computed by:

TISR of TBM Gripper = ∑ISR of TPM Gripper (TL+TC+TD+GC+WT)

TISR of TBM Gripper = 0.7105 +1.1781+1.1408+2.403+1.5841

TISR of TBM Gripper = 7.0165

Road Header Influences of Suitability Rating (ISR)

In order to define influences of suitability rating of Road Header; table 2 shown below depict that suitability equipment selection score and weight of effective factor for Road Header.

Tunnel Length (TL)

ISR of tunnel length = WEF of tunnel length*SESS of tunnel length

ISR of TL = WEF of TL*SESS of TL

ISR of TL = 0.22*7.5

ISR of TL = 1.65

Table 2 Suitability equipment selection score and Weight of effective factor of Road Header

Road Header		
Factors	Suitability Equipment Selection Score (SESS)	Weight of Effective Factor (WEF)
Tunnel Length (TL)	7.5	0.220
Tunnel Cross Section (TC)	6.6	0.194
Tunnel Depth (TD	5.2	0.152
Geotechnical Condition (GC)	7	0.205
Water Table Level (WT)	7.8	0.229

Tunnel Cross Section (TC)
ISR of tunnel cross section = WEF of tunnel cross section*SESS of tunnel cross section
ISR of TC = WEF of TC*SESS of TC
ISR of TC = 0.194*6.6
ISR of TC = 1.2804

Tunnel Depth (TD)
ISR of tunnel depth = WEF of tunnel depth*SESS of tunnel depth
ISR of TD = WEF of TD*SESS of TD
ISR of TD = 0.152*5.2
ISR of TD = 0.7904

Geotechnical Condition (GC)
ISR of geotechnical condition = WEF of geotechnical condition*SESS of geotechnical condition
ISR of GC = WEF of GC*SESS of GC
ISR of GC = 0.205*7
ISR of GC = 1.435

Water Table Level (WT)
ISR of water table level = WEF of water table level*SESS of water table level
ISR of WT = WEF of WT*SESS of WT
ISR of WT = 0.229*7.8
ISR of WT = 1.7862

Therefore; the total sum of influences of suitability rating (TISR) for Road Header was computed by:
TISR of Road Header = ∑ISR of Road Header (TL+TC+TD+GC+WT)
TISR of Road Header= 1.65+1.2804+0.7904+1.435+1.7862
TISR of Road Header= 6.942

In General; the maximum value for total sum of influences of suitability rating (TISR) was considered and selected as most preferable tunnel boring machine for specified project site. As a result; TPM Gripper was selected as tunneling machine for the project area.

3. DISCUSSION

In any engineering project selecting appropriate method of excavation was governing issues. In tunnel construction selecting appropriate tunneling equipment was the goal of this case study. In selection of tunneling equipment from different Multi-Criteria Analyzes (MCA) approach particularly Analytic Hierarchy Process (AHP) was used for this study. As a result; in line with the above information weight of effective factor (WEF) depict that Geological condition weighting 0.267 of the area basically affect the suitability of TBM Gripper and Water Table level weighting 0.229 was affect the suitability of the Road Header in this project. In this case study; Total sum of Influences of Suitability rating (TISR) was used to define the probable tunneling equipment for this project. As a result; the study considers TBM Gripper and Road Header as optional tunneling machine. The result of the study depict that the maximum Total sum of Influences of Suitability rating (TISR) was the governing one and considered as Tunnel boring machine for this project. Consequently; TPM Gripper with a value of 7.0165 Total Sum of Influences of Suitability Rating was considered as tunneling equipment or machine for specified railway project. TPM Gripper was selected as tunnel boring machine for specified project site.

4. CONCLUSION

Tunneling was a techniques used to excavate tunnel in specified project. Based on the availability of tunnel boring machine; the two optional tunneling considered in this project site was TPM Gripper and Road Header in order to undertake tunnel excavation. For further analysis Multi-Criteria Analyzes (MCA) approach particularly Analytic Hierarchy Process (AHP) was used for this study. In order to undertake tunneling tunnel length, tunnel cross section, tunnel depth, geotechnical condition and water table level was considered as main factors influencing tunneling. As per the area of the study; Suitability of equipment selection score of those factors were obtained from suitability equipment selection chart for both tunnel boring machine. The result of suitability equipment selection score showed that (4.9, 6.3, 6.2, 9, 7.3) and (7.5, 6.6, 5.2, 7, 7.8) were scores for TBM Gripper and Road Header respectively. Based on the suitability equipment selection score; weight of effective factor for both tunneling machine was obtained. The result of weight of effective factor depict that Geological condition weighting 0.267 of the area basically affect the suitability of TBM Gripper and Water Table level weighting 0.229 was affect the suitability of the Road Header for specified project site. Even if; those factor hinder the selection of those tunnel boring machine at maximum level the selection of the tunneling machine was considered based on influences of suitability rating of the machine. As a result the cumulative effects of those tunneling factors bring the most probable tunnel boring machine for the selected project site. From the cumulative effect of those factors the result shows 7.0165 and 6.942 influences of suitability rating for TBM Gripper and Road Header respectively. As a result; TBM Gripper valuing the maximum Influences of Suitability Rating with 7.0165 was considered as tunneling machine for specified project site. TPM Gripper was the most probable tunnel boring machine for specified task.

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Statement of Declaration

I declare that the research entitled “Tunnel Boring Machine Selection in Railway Project (Case Study)” was my original work and it hasn’t been presented for the award of any other similar titles by other researchers.

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